CHAPTER 6. STEEL SHORING SYSTEMS

6-1.01 Introduction

As used in this manual, the term "steel shoring system" describes falsework consisting of individual components which may be assembled and erected in place to form a series of internally-braced steel towers of any desired height. The tower legs, either directly or through a cap system, support the main load-carrying members.

From a design standpoint, shoring "towers" are indeterminate space frames; consequently, they cannot be analyzed by the general formulas applicable to statically determinate framed structures. Instead, determining the ability of steel shoring to safely carry a given load involves the use of empirical criteria developed from a consideration of the effect of such factors as tower height, differential leg loading, sidesway and method of external support.

Depending on load-carrying capacity, steel shoring systems are classified as pipe-frame systems, intermediate strength systems and heavy-duty systems. This chapter discusses the criteria and procedures to be followed when reviewing steel shoring systems for compliance with the falsework specifi-cations.

6-1.02 Safe Working Loads

Steel shoring is a "manufactured assembly" within the meaning of this term as it is used in the specifications. Therefore, the maximum load to be carried-may not exceed the safe working load recommended by the manufacturer for any given loading condition.

Safe working loads for all shoring systems now in use have been determined empirically from full-scale load tests. In all cases of record, maximum values were obtained during tests in which the legs of the test tower were loaded uniformly and concentrically, the tower was supported on a concrete pad to ensure an unyielding foundation, and the top of the tower was externally braced to prevent appreciable lateral movement. Results of tests in which the towers were loaded eccentrically and/or lateral movement was allowed indicate a substantial reduction in capacity.

Shoring capacity as shown in catalogs or brochures published by the manufacturer should be considered as the maximum load which the shoring is able to safely support under ideal. loading conditions. These maximum values should be reduced for adverse loading conditions often encountered in bridge falsework. For example, horizontal loads, eccentricity due to unbalanced spans or pouring sequence, and uneven foundation settlement are but a few of the loading conditions typical of bridge falsework which differ from the loading conditions upon which the manufacturer's ratings are based.

Finally, the maximum allowable safe working load as recommended by the manufacturer is based on the use of new material, or used material in good condition. If shoring components are not in good condition, the maximum allowable working load must be reduced by the contractor in accordance with contract requirements.

6-l-03 Pipe-Frame Shoring Systems

As the name implies, the various components which make up a pipe-frame shoring system are fabricated from sections of steel pipe of various diameters. The basic unit is the base frame, which consists of two vertical members; or legs; and connecting braces welded together to make a single, rigid unit.

Base frames, which are six feet in height, are erected in pairs and fastened together with pin-connected diagonal braces. Pairs of braced base frames are stacked one above the other to form the falsework towers. Typically, the towers are four feet wide (which is the width of a base frame) and eight feet long.

Two types of base frames are in general use. These are the ladder type and the cross-braced type. In the ladder type, frame rigidity is provided by horizontal struts between the vertical legs, whereas in the cross-braced type rigidity is enhanced by diagonal cross-bracing between the legs.

Extension frames are used with cross-braced base frames to extend the height of the tower, in one-foot adjustments, up to five feet. Extension frames, which are the same width as the base frames, may be used at either the top or the bottom of a tower. Minor height adjustments are accomplished with screw jack extensions at the top and bottom of each tower leg.

The height of ladder-type frames is adjusted in 4-inch increments up to five feet by means of a single-post extension staff at the top of each tower leg. Screw jacks are used at the bottom of the base frames for minor adjustments.

Pipe diameter is the same for both types, Typically, 2.375-inch pipe is used for the base frames and 1.90-inch pipe for extension frames and staffs.

6-l.03A Allowable Loads for Cross-Braced Frames

The load-carrying capacity of shoring constructed of cross-braced frames is governed by the strength of the frame legs. When loaded, the legs act as short, pin-connected columns having an unsupported length equal to the height of the frame plus the height of the screw jack.

The maximum allowable load per leg for pipe-frame shoring (cross-braced type) is limited by the height of the extension frame and the type of screw jack (swivel or fixed head) used at the top of the frame. If swivel-head screw jacks are used, maximum allowable leg loads are as shown in the following tabulation:

Maximum Allowable Leg Load in Pounds

Extension frame height	2'0"	3’0”	4'0"	5'0"
Screw height 12" or less	11000	11000	10000	9400
Screw height exceeds 12"	8200	8200	8000	7800

If fixed-head screw jacks are used at the top of the extension frame, the allowable load per leg will be 11,000 pounds for all extension frame heights up to five feet for screw jack height of 12 inches or less. No increase will be permitted in the tabulated values when screw jack height exceeds 12 inches, regardless of the type of jack used.

Extension frames must be braced. Side cross-braces are required for extension heights up to 2'O". Both side and end cross-braces are required for 3'0" to 5'0" extension heights.

The allowable design loads are va1id only if the materials are in good condition, and only if the shoring is properly braced and erected in accordance with the manufacturer's recommendations and the criteria set forth in Section 6-l.03C, Analysis of Pipe-Frame Shoring Systems.

6-l.03B Allowable Loads for Ladder-Type Frames

The load-carrying capacity of shoring constructed of ladder-type frames may be governed by the height of the tower or, if used, by the height of the extension staff.

Because of its substantially lower load-carrying capacity, shoring constructed with ladder-type frames is not practical for use as bridge falsework, If it should be encountered, the maximum allowable design load will be limited by Division of Structures policy to the following values, regardless of any conflicting information which may be found in manufacturer's catalogs or brochures:

> If the shoring system consists of a single tier of braced base frames, leg loads shall not exceed 10,000 pounds.
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> If the shoring system consists of two or three tiers of base frames, leg loads shall not exceed 7,500 pounds.
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> If an extension staff is used, the maximum allowable leg load shall be reduced to 6,000 pounds.

Maximum allowable leg loads as set forth above will apply when fixed-head screw jacks are used, or when swivel-head jacks are used at either the top or the bottom of the tower. Screw jack extension is limited to 12 inches. The use of swivel-head *screw* jacks at both-top and bottom of ladder-type frames is not permitted.

For any combination of base frames or base frames with staff extension, the total height of the shoring shall not exceed 20 feet overall, including screw jack extensions.

6-1.03C Analysis of Pipe-Frame Shoring Systems

The use of pipe-frame shoring as bridge falsework must conform to the criteria set forth in this section. Review procedure is as follows:

1. Investigate Tower Leg Loads

   Tower leg loads should not exceed the limiting values under any loading condition *or* sequence. As previously noted, these values are based on the use of new material, or material in good used condition.

   The maximum load on one leg of a frame should not exceed four times the load on the other leg under any given loading condition or sequence.

   The maximum load on one of the two frames making up a tower should not exceed four times the load on the opposite frame under any given loading condition or sequence.

2. Determine Supplemental Bracing Requirements *

In the transverse direction (the direction parallel to the frame) no supplemental bracing is required for tower. heights of 20 feet or less. For heights exceeding 20 feet, the individual towers making up the shoring system cannot resist the combined effect of both vertical and horizontal loads without overstressing the tower components unless supplemental bracing is provided. Therefore, when the shoring height reaches four frames, including an extension frame if used, one horizontal brace and one diagonal brace must be attached to each tower face, for every three frames of shoring height. The lowest horizontal brace should be located near the top of the third tower frame, and any additional horizontal braces spaced no farther than three frames apart. The diagonal braces should be located on opposite tower faces, and should run in opposite directions.

When superelevation exceeds six percent, a transverse brace shall be attached to one tower face of the top frame. This brace shall be in addition to bracing required by the preceding paragraph.

In the longitudinal direction, no bracing is required when shoring height is less than six frames. When shoring height is six frames or more, a horizontal brace is required on one face of each tower, with the lowest brace located no higher than the fourth frame and any additional braces spaced no farther than four frames apart.

Supplemental bracing, when required by the criteria set forth herein, must be shown on the falsework drawings. Design details, Including the method and exact location of the connecting devices, must be in accordance with the manufacturer's recommendations.

3. Investigate System Stability

When continuous caps or joists are used, pipe-frame shoring will be considered as capable of resisting all horizontal forces, including wind, provided the shoring

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* Supplemental bracing requirements apply only to pipe-frame shoring systems with cross-braced base frames because, as previously noted, the height of shoring constructed with ladder-type frames is limited to 20 feet.

is property braced in accordance with the criteria set forth in the preceding paragraphs, and provided the shoring system is stable against overturning. As used herein, the term "shoring system" means the full width of the properly-braced falsework supporting continuous caps or joists.

If the height-to-width ratio of the shoring system, as defined above, is 1.0 or less, the system will be considered as stable against overturning and further analysis will not be required.

If the height-to-width exceeds 1.0, overturning stability should be investigated. For analysis, the resisting moment will be assumed as acting about the downwind edge of the system. If the resisting moment of the system exceeds the overturning moment, the falsework is stable against overturning. If the resisting moment is less than the overturning moment, the difference must be resisted by cable guys or other means of external support. (See Section 5-1.05, Overturning.)

4. Investigate Foundation Support

The specifications do not include any express provisions governing the design of foundations for pipe-frame shoring; however, the method of foundation support is part of the falsework design and should receive the same consideration as the foundation for a conventional falsework system.

6-1.04 Intermediate Strength Shoring

Steel shoring consisting of cross-braced tubular members capable of carrying 25 kips per tower leg with a 2-l/2 to 1 safety factor is marketed commercially as "WACO SHORE 'X' 25K" vertical shoring.

This shoring system has had only limited use in California. In concept and design it is similar to the cross-braced pipe-frame shoring system described in the preceding section; however the individual components are larger.

The use of the Shore "X" 25-kip system will be governed by the following conditions and limitations:

1. The maximum load carrying capacity of 25 kips per leg is based on the use of fixed head screw jacks at the top and bottom of the towers. If swivel-head screw

jacks are used at either the top or bottom of the tower, the maximum load must be reduced to 20 kips per tower leg.

2. Maximum screw-jack adjustment may not exceed 14 inches.

3. Extension frames must be braced. Side cross-braces are required for all extension-frame heights. In addition, end cross-braces (braces across the face of the extension frame) are required for extension frame heights of 3'0" or more.

4. The maximum load on one leg of a frame, or on one frame of a tower, should not exceed four times the load on the opposite leg or frame under any given loading condition or sequence.

5. When tower height reaches four frames, including an extension frame if used, supplemental bracing must be provided in accordance with the criteria in Section 6-1.03C. Analysis of Pipe-Frame Shoring Systems, except that no supplemental bracing will be required in the longitudinal direction.

6. When investigating system stability, follow the procedure in Section 6-l.O3C, Analysis of Pipe-Frame Shoring Systems.

The use of WACO 25-kip shoring, when designed and erected in conformance with the criteria set forth above, is authorized for tower heights up to 37'-4", which is five frames plus a fully-extended extension frame plus the maximum allowable screw-jack adjustment. For any proposed use exceeding this limiting height, the contractor must furnish a statement signed by the shoring manufacturer covering the specific installation. The statement must expressly provide that the shoring will carry the loads to be imposed without over-stressing any shoring component or reducing the required safety factor. Note that the statement is a condition of approval of the falsework design. If the contractor cannot or does not furnish the statement, the falsework drawings will not be approved.

The method of foundation-support is relatively more important for intermediate strength shoring than for pipe-frame shoring because the leg loads are considerably higher. Accordingly, the foundation design should be scrutinized to ensure that the vertical loads are uniformly distributed and differential settlements are minimized.

6-1.05 Heavy-Duty Shoring Systems

Heavy-duty shoring is capable of carrying up to 100 kips per tower leg. Two systems are in general use in California. These are the WACO and PAFCO Shoring Systems, both of which are designed and manufactured to carry a 100-kip leg load with a 2-l/2 to 1 safety factor.

The criteria for review of heavy-duty steel shoring, as set forth in this manual, were developed by the Division of Structures from a subjective evaluation of manufacturer's published test data together with an analysis of mathematical models of both the WACO and PAFCO towers. Accordingly, the criteria will apply only to the WACO and PAFCO Systems. Should some other type of heavy-duty shoring be proposed for use, the engineer should consult with bridge Headquarters *for* the review procedure to be followed.

Review of the falsework design to verify contract compliance will be based on the criteria in the following section, except that designs based on alternative criteria may be approved provided the contractor furnishes a written statement from the shoring manufacturer coveting said alternative criteria. The statement must refer to the specific project on which the alternative criteria will apply, must set forth the conditions under which the particular alternative criteria may be fol- lowed, and must expressly provide that a design based on the alternative criteria will not overstress any shoring component nor reduce the required safety factor.

Finally, when reviewing heavy-duty shoring designs, keep in mind that the criteria set forth in the following section are based on the assumed use of a propriatory shoring system which, during its lifetime, has not been altered or modified in any way. This is an important point, because both WACO and PAFCO shoring in which components have been modified to fit a particular job situation is known to exist. Such modified shoring, if used on a California contract, would have been covered by a manufacturer's statement certifying the modifi- cation and use. Once modified, however, any subsequent use must be covered by a new statement certifying that the modified shoring will carry the actual loads to be imposed without overstressing any tower component or reducing the required safety factor.

6-1.O5A Review Criteria

If tower legs, including an extension unit if used, are utilized as single-post shores braced in one direction only, the shores should be analyzed as individual steel columns.

STEEL SHORING SYSTEMS

Since the unsupported column length will be the total height of the shore, measured from bottom of base plate to cap, the computed allowable load (based on the column formula) may be substantially less than the safe working load recommended by the manufacturer,

If the total height of the shoring does not exceed the height of a single tower unit, including an extension unit if used, and if both the base and extension units are fully braced in both directions in accordance with the manufacturer's recommendations, individual tower legs may be considered as capable of carrying the safe working load recommended by the manufacturer without regard to the load on adjacent legs.

If the shoring system consists of two *or* more units stacked one above the other, either with or without an extension unit, the differential leg loading within a given tower unit should not exceed the following limitation:

Maximum load on any leg in the tower unit	Maximum to minimum load ratio
10 kips or less	10 to 1
11 kips to 50 kips	6 to 1
51 kips to 75 kips	5 to 1
76 kips *or* more	4 to 1

In any case where the actual loading condition during any construction stage will produce a differential leg loading in excess of the ratio shown, the contractor must furnish documentation that the actual loads are in accordance with the shoring manufacturer's recommendations. The documentation must be in the form of a written a statement by the manufacturer covering the specific installation, and must expressly provide that the towers will withstand the actual loading differential without overstressing any tower component or reducing the required safety factor. In the absence of such supporting documentation, the falsework drawings will not be approved.

Steel beams used as continuous caps over two or more tower units require a complete stress analysis to determine the effect of continuity on tower leg loads. In many cases, and particularly where large skews are involved, the falsework stringers will not be supported directly over a tower leg; consequently, both positive and negative bending moments will occur in the cap. Resulting moment shear must be added to *or* subtracted from the simple beam reaction to obtain the actual leg load, and this may produce-a significant load differential. Also, do not overlook the effect of differential leg loads, and the resulting differential settlement, on actual unit stresses in the cap itself.

The use of "double legs" in which lateral support of the supplemental leg is provided by the main tower leg rather than independent bracing will be permitted with no reduction in tower load-carrying capacity, provided the proposed double-leg configuration is shown in the manufacturer's catalog or technical data furnished by the contractor. However, the use of "triple legs" will not be approved unless the contractor furnishes a statement from the manufacturer covering the specific installation. The statement must expressly provide that the use of supplemental legs will not overstress any tower component, nor reduce the required safety factor.

In any case where the maximum leg load within a given tower exceeds 30 kips, the specifications require the tower foundation to be designed and constructed to provide uniform settlement under all legs of the tower under all loading conditions. This requirement is included in the specifications to prevent distortion of the tower components as a consequence of unequal leg settlement.

The method of foundation support must be shown on the falsework drawings in sufficient detail to permit a stress analysis. When reviewing the foundation design, keep in mind that timber pads or cribbing, while generally adequate for conventional falsework construction, may not ensure uniform settlement under the heavier loads carried by heavy-duty shoring systems. When asked, tower manufacturers will generally recommend concrete to ensure an unyielding foundation. Under adverse foundation conditions, CIDH piles may provide the most economical solution.

The effect of unequal leg settlement becomes increasingly severe as leg loads increases, consequently, the tower foundation design, including the method employed to ensure uniform settlement, is relatively more important when leg loads are high.

In the case of high falsework, differential leg shortening may be an important consideration and should be investigated. Note that differential leg shortening (which will occur under a differential leg load condition) has the same effect on a continuous cap as differential leg settlement, and will result in a further distribution of vertical forces.

The adverse effect of lateral movement at the top of a tower (sidesway) on total load-carrying capacity is not subject to precise analysis, as the calculations involved are highly indeterminate. In theory, both the PAFCO and WACO 100-kip shoring systems in use today can tolerate some sidesway without overstressing the tower components; however, the amount of acceptable movement depends on total tower load, tower height and other variable factors so that limiting values become difficult to establish.

In view of this, it is Division of Structures policy to require heavy-duty shoring to be cable-guyed or otherwise externally supported at the top unless the towers are stable against overturning as defined in Section 5-1.O5A, Calculation of Resisting Moments. Division policy further provides that falsework towers which are stable against overturning, or which are externally braced *or* cable-guyed to prevent over-turning, will be considered as stable against internal collapse as well. This approach, while not academically exact, is conservative and will greatly facilitate analysis.

The total resisting moment of a falsework bent composed of two or more towers having a common *or* continuous cap will be assumed as equal to the sum of the resisting moments of the individual towers. In such cases the cap will be considered as capable of distributing horizontal forces- equally between towers, but not capable of-applying moment to a tower.

In a multiple-tower bent where a continuous cap is not used, each tower must be independently braced to resist the horizontal load applied to that tower because the supported falsework above the towers is not capable of transferring horizontal forces.

When investigating the stability of a multiple-tower bent, any advantage gained from the theoretical transfer of the point of application of the vertical forces as the towers start to tip will be neglected.

When designing external bracing, including cable bracing, particular attention must be given to the method by which the bracing is connected to the falsework. Connections must be designed to transfer horizontal and vertical forces from the falsework to the bracing system without overstressing any tower component.

The importance of adequate external bracing, when external bracing is required to ensure the stability of a falsework tower, cannot be over-emphasized. The bracing system, including all construction details, must be shown on the falsework drawings, and should be reviewed for compliance with contract requirements in the same manner as all other components of the falsework system.